Lepton-nucleon interactions at the next-to-the-leading order

A. Aleksejevs[1] and S. Barkanova[2]

[1] *Division of Science, SWGC, Memorial University, Corner Brook, NL, A2H 6P9, Canada*
[2]*Department of Physics, Acadia University, Wolfville, NS, B4P 2B2, Canada*

Next-to-Leading-Order (NLO) effects play a crucial role in tests of the Standard Model (SM), and require careful theoretical evaluation. Electroweak physics, which has just entered the precision age, is an excellent place to search for new physics, but also requires considerable theoretical input. We show how we applied computational packages such as FeynArts, FormCalc, Form and LoopTools for the evaluation of one-loop electroweak and hadronic radiative corrections.

I. INTRODUCTION

With recent advances in the automatization of the (NLO) calculations, it is reasonable to consider these methods in the applications towards the electro-weak and hadronic processes. Computer packages such as FeynArts [2], FormCalc, LoopTools [3] and Form [4] created a possibility to perform such type of calculations. In the work presented here, we extend FeynArts for the NLO symbolic calculations of amplitude or differential cross section. Using Dirac and Pauli type couplings, we construct the computational model [5] enabling us to deal with electron-nucleon scattering up to NLO level. Using this model we compute parity-violating asymmetries up to NLO level in electron-proton (e-p) scattering. Additionally we have developed an extension named Computational Hadronic Model (CHM) [7] of the FeynArts towards the hadronic sector using the Chiral Perturbation Theory (ChPTh). Later we have applied CHM to extract strong coupling constants arising in the chiral lagrangian from the experimental branching ratios (BR) for the following processes: $\Sigma^{*+} \to \Sigma^0 + \pi^+$, $\Sigma^{*-} \to \Lambda + \pi^+$, $\Xi^{*0} \to \Xi^{*-} + \pi^+$ and $\Delta^{++} \to p + \pi^+$.

II. ELECTROWEAK SECTOR

Electroweak properties of the nucleon can be studied by parity-violating electron-nucleon scattering at low energies. Such experiments can measure the asymmetry coming from the difference between cross sections of left- and right-handed electrons ($A = \frac{d\sigma_+ - d\sigma_-}{d\sigma_+ + d\sigma_-}$). This asymmetry between left- and right-handed particles is clearly predicted in the Standard Model (SM) of particle physics. Extracting the physics of interest from the measured asymmetry requires evaluating NLO contribution to electroweak scattering at very high precision. The dominant contribution normally comes from the Leading Order (LO) correction in perturbation theory. The NLO effects in the physics of the electroweak interactions plays a crucial role in the tests of the Standard Model. In this project, we took into consideration the NLO effects in parity-violating lepton scattering and have computed radiative corrections to the parity violating asymmetries. In general, we have extended FeynArts by including Dirac and Pauli form factors in couplings taken in the dipole/monopole form without strange quark contribution. Calculations were done in the on-shell renormalization scheme using Feynman gauge. Detailed description of this model is given in [5]. To avoid the infrared divergences, we have treated the final asymmetries with both Soft and Hard Photon Bremsstrahlung (SPB+HPB) [8] contributions. Computed results for the asymmetry are given in the Fig.[1a] for the range of the momentum transfers up to $1.0\,GeV^2$ in the forward scattering.

It is clear from Fig.[1a] that NLO PV effects are of the order of 20%. Also we can see that our results are in excellent agreement with theoretical predictions of G0 group [1]. Comparing our predictions with the G0 [1] experimental asymmetry we can conclude that there is an evident discrepancy between theory and experiment. Recalling the fact that our calculations were completed without an account for the sea of the strange quarks in the nucleon, good explanation to this would be a non negligible strange content of the nucleon. Moreover, we have used a model dependent form-factors and it is reasonable to investigate impact

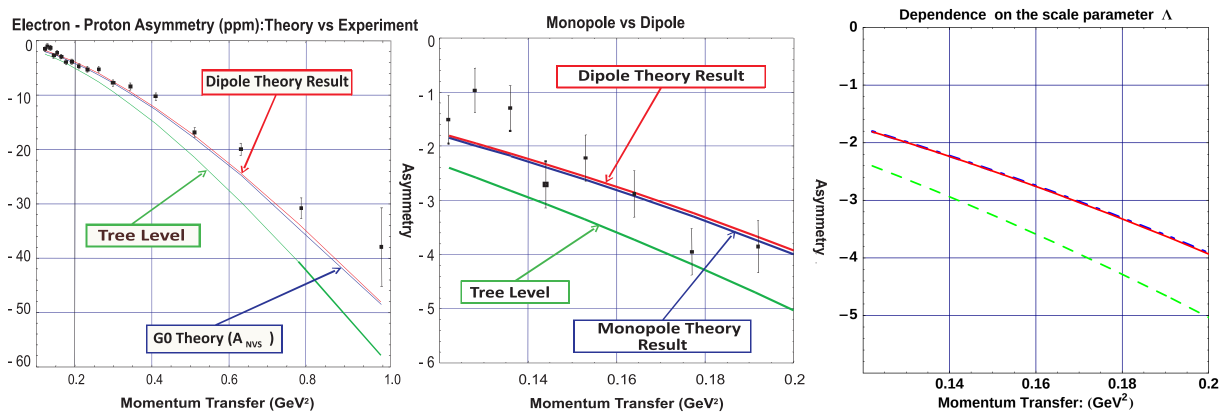

Figure 1: a) Asymmetry for the PV electron-proton scattering is given on the left figure. Dipole theory results are given by LO+NLO contributions, and A_{NVS} is no-vector-strange asymmetry given in [1]. b) Figure in the centre shows the difference in the asymmetries for monopole and dipole formfactors. c) Figure on the right shows the difference in asymmetries for the two limiting values of scale parameter, $\Lambda^2 = 0.4 \cdot m_N^2$(solid red curve) and $\Lambda^2 = 2.0 \cdot m_N^2$(dashed blue curve). Dashed green curve is a leading order contribution.

of this model dependence on calculated asymmetries. In this case we looked at the difference between monopole and dipole results and dependence on the scale parameter Λ (see Fig.[1b,c]). From Fig.[1b,c] it is evident that calculations of the asymmetries are independent of the choice of the type of form-factors and have virtually no dependence on the scale parameter Λ. Although model dependence will become evident when calculating absolute cross sections, for the asymmetries calculations presented results are model independent. We also reserved the kinematic dependence in all types of our radiative corrections. It will make it easier to adopt our results to the current and future parity-violating experiments for any lepton-hadron scattering processes.

III. HADRONIC SECTOR

Tremendous success of the ChPTh in the description of the hadronic interactions in the non-perturbative regime of the QCD attracted attention of the physics community for decades. To calculate amplitudes or cross sections, we need a theoretical input at the NLO retaining full kinematic dependencies. To date, there are several packages (FeynArts, FormCalc, FeynCalc and Form) allowing us to produce semi-automatic calculations in the high energy physics. Although FeynArts and FormCalc were originally designed for SM calculations, the flexibility of the programs allows us to extend them to interactions appropriate for the hadronic sector. This was a main reason to use FeynArts and FormCalc as a base languages for the automatization of chiral hadronic calculations. Here we have used a CHM which detailed description reader can find in [7]. As an application and test of this model, we decided to extract strong coupling constants of ChPTh from the experimental values of BR to decays of resonances to baryons, such as: $\Sigma^{*+} \to \Sigma^0 + \pi^+$, $\Sigma^{*-} \to \Lambda + \pi^+$, $\Xi^{*0} \to \Xi^{*-} + \pi^+$ and $\Delta^{++} \to p + \pi^+$. The BR are centered about 1.4, 1.4, 1.3 and 1.5 respectively and as it is expected, leading order calculations are SU(3) conserving and will result in equally valued BR. This fact prompts us to look at the NLO corrections. The NLO calculations were completed with an account of the octet of mesons, baryons and decuplet of resonances participating in the one loop diagrams. If we take experimental BR and fit strong coupling constants C and H to the values of BR we can reproduce results predicted earlier in [6]. For the each decay outlined earlier in this article, parametric plots for the C coupling constant as a function H are shown in Fig.[2].

From Fig.[2] it is clear that all curves indicate the central value of the C coupling constant is around $|C| = 1.0 \pm 0.2$. From this we can derive constrains on the H coupling constant as $H = -1.5 \pm 0.5$. Our predictions are consistent with the results of [6]: $|C| = 1.2 \pm 0.1$ and $H = -2.1 \pm 0.7$. In general, these

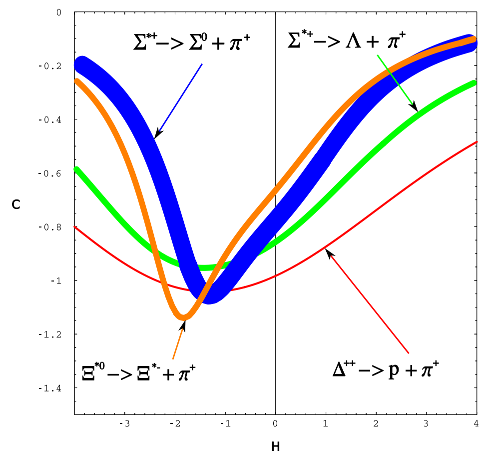

Figure 2: Parametric plots for the strong coupling constants C and H fitted to the BR of $\Sigma^{*+} \to \Sigma^0 + \pi^+$, $\Sigma^{*-} \to \Lambda + \pi^+$, $\Xi^{*0} \to \Xi^{*-} + \pi^+$ and $\Delta^{++} \to p + \pi^+$. Thickness of the curves represents the experimental uncertainty taken from the BR for these decays.

calculations served us as an excellent test of rather involved computer based calculations. The results of the CHM can be expressed analytically, using FormCalc with an amplitude expressed in the Passarino-Veltman basis as well as numerically with application of the package LoopTools. The future applications of the CHM can be seen in the automatization of the calculations of NLO radiative corrections for the production/decay channels of hadronic physics.

IV. ACKNOWLEDGMENT

This work has been supported by an NSERC Discovery Grant.

References

[1] G0 Collaboration, arXiv:nucl-ex/0506021v1.
[2] T. Hahn, Comput. Phys. Commun. 140 (2001) 418, hep-ph/0012260.
[3] T. Hahn, M. Perez-Victoria, Comput. Phys. Commun. 118 (1999) 153 , hep-ph/9807565.
[4] J.A.M.Vermaseren, math-ph/0010025.
[5] A Aleksejevs, S. Barkanova and P. Blunden, J. Phys. G: Nucl. Part. Phys. 36, 045101, (2009).
[6] M. Butler, M. Savage, R. Springer, Nuclear Physics B 399, Issue: 1, (1992).
[7] A. Aleksejevs and M. Butler, arXiv:0710.3580 (2007).
[8] A. Aleksejevs, S. Barkanova, P. Blunden and N. Deg, arXiv:0707.0657 (2007).